A SUBMILLIMETER WAVE S1S HETERODYNE RECEIVER USING Nb TUNNEL JUNCTIONS WITH INTEGRATED TUNING CIRCUITS FOR 626 GHz.

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L INTRODUCTION

So far, the most sensitive heterodyne receivers in the millimeter-wave and submillimcter-wave frequency ranges have used the mixing response of the quasiparticle currents in S1S (Superconductor-Insulator-SuWrconductor) tunnel junctions. Both high RF-to-IF conversion efficiency and low noise arc predicted by theory [1], and recently good results have been reported up to frequencies near 600 GHz [2-4]. We have designed, built and characterized an S1S receiver using niobium-based tunnel junctions, for astronomy observations of several important molecular transitions in the range 600 GHz -635 GHz. We report double sideband (DSB) receiver noise temperatures $T_R < 395$ K for frequencies below 630 GHz, and as low as 250 K at 605 GHz - 610 GHz. These results confirm that quasiparticle S1S mixers work wc]] at submillimeter wave frequencies corresponding to photon energies of at least 90% of the superconductor gap energy.

11. RECEIVER DESIGN

The receiver employs a full-height waveguide S1S mixer, with an adjustable backshort and E-plane tuner to provide a wide range of embedding impedances [51. The RF signal is coupled to the input waveguide via a dual-mode conical horn. A two-section Chebychev transformer converts the 1.4-GHz IF output impedance to the 50-Q input impedance of the cooled low-noise HEMT amplifier. The measured IF bandwidth is 500 MHz.

The local oscillator (LO) consists of a 104-GHz Gunn oscillator followed by two frequency multipliers (x2x3) using whisker-contacted Schottky varactor diodes. The LO and signal arc diplexed by a mylar beamsplitter having a 15% reflection which gives enough LO power to fully optimize the mixer performance at each frequency. To avoid excessive insertion losses associated with dielectric lenses at such high frequencies, we use off-axis elliptical mirrors to couple the RF power into the mixer. In addition, two fluorogold infrared filters prevent room temperature radiation from saturating the mixer. A superconducting magnet (producing up to 1000 Gauss) is used to average out the AC Josephson current which is a source of noise for the quasiparticle mixer.

111. S1S JUNCTION AND INTEGRATED TUNING CIRCUIT

The mixer uses a 0.25-μm^2 Nb/AlO$_x$/Nb tunnel junction of high current density ($J_c \approx 13$ kA/cm^2),
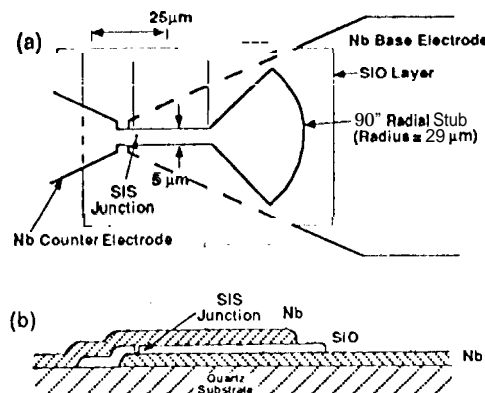

Fig. 1. (a) Top and (b) cross section views of the microstrip tuning circuit integrated with the S1S tunnel junction.

fabricated by electron-beam lithography [6]. The normal resistance is 73 Ω. Its large capacitive susceptance, which shunts the RF signal, is resonated out by a parallel superconductive Nb/SiO/Nb microstrip circuit. This circuit, shown in Fig. 1, was designed for an estimated junction capacitance C of 21 fF and a center frequency of 626 GHz. A radial stub provides an RF short circuit over a broad bandwidth, which is then transformed into the desired inductance by an appropriate section of microstrip transmission line of characteristic impedance near $(\omega C)^{-1}$. Calculations of the transmission line parameters took into account the effect of the magnetic penetration depth (750 Å) in both superconducting electrodes, but neglected possible effects of dispersion in the line.

IV. RESULTS AND DISCUSSION

The receiver double sideband (DSB) noise temperature as a function of LO frequency is shown in Fig. 2. The best noise temperature is 250 K ± 17 K at 605 GHz - 610 GHz. The highest is 508 K ± 30 K at 635 GHz. For each point, the waveguide tuners, LO power and DC bias were optimized. The rise in noise temperature near 635 GHz may indicate the edge of the mixer tuning range, determined by both the waveguide mount and the integrated tuning circuit, The latter was designed to optimize the mixer at -626 GHz. However, the DC spike induced in the I-V characteristic by the interaction of the AC Josephson current with the integrated circuit indicates that the resonance may actually occur near 580 GHz. Uncertainties in the magnetic penetration depth and/or in the junction capacitance could account for this frequency shift, The same junction has been measured in another receiver, designed to operate at 547 GHz, and those results have been reported elsewhere [4].
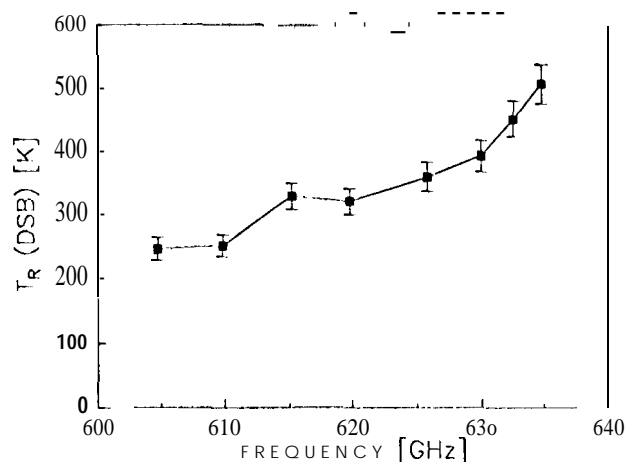
Fig. 2. Double sideband receiver noise temperature vs LO frequency

The receiver performance was measured by the "Y-factor" method using hot (295 K) and cold (82 K) loads at the RF signal input, and the full Planck expression was used to calculatc the radiated power from thcse loads. Figure 3 shows the corresponding IF output power curves, along with the unpumpcd and LO-pumpcd I-V characteristics. The bcst rcceiver noise was obtained when the junction was biased in the high voltage end of the photon step, that is, above the large dip that can bc seen in the IF output power curve. Wc bclievc this dip results from an overlap of the first-order photon step of the positive voltage region with the second-order photon step of the negative voltage region, The latter dccrcascs the pumped current of thc positive **voltage step in the region** of overlap. This feature is clearly seen in all pumped I-V characteristics for high LO powers. The dip in the IF power curve is produced by an IF impedance mismatch near where the overlap ends, Both ·the LO power and LO frcqucncy dcpcndcncc of this I-V/IF feature support this interpretation. This effect has been predicted theoretically and observed at 73 GHz [7], but this is the first identification of it at submillimctcr wave frequencies.

This effect has practical consequences for submillimctcr wave receivers. With niobium-based junctions, the bias voltage region yielding the best mixing performance will be restricted to only a small fraction of the first photon step. As frequency approaches the gap frequency, the second photon stcp eventually ovcriaps the wholc photon stcp of interest, reducing the optimum mixing bias region to zero. In addition, the second Shapiro step occupies this critical bias region. These considerations arc incentives for utilizing higher energy gap materials, such as NbN, for S1S mixers operating at still smaller wavelengths.

V. CONCLUSION

We have dcvclopcd and characterized a wavcguide S1S hctcrodyne rcceiver showing low noise performance in the range 600 GHz to 635 GHz (as low as 250 K). These results indicate that Nb tunnel junctions and Nb transmission lines work well at high submillimctcr wave frequencies. This rcceiver is schcdulcd for radioastronomy observations at the Caltcch Submillimctcr Observatory on Mauna Kca, in Hawaii.

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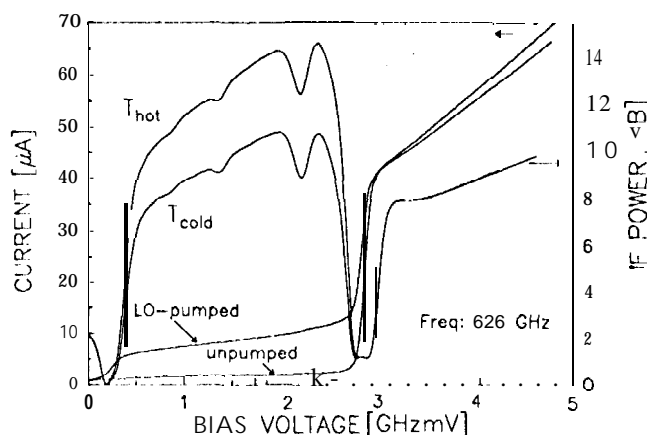[7] D. Winkler, T. Clacson, *J. Appl. Phys.* 26, p 4482, 1987.

Fig.3. Typical IF output power vs bias voltage for hot and cold loads at the receiver input, showing the effect of the overlapping photon steps. Also shown arc the LO pumped and unpumpcd I-V characteristic.